Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 12 (5): 208-213, 2013
ISSN 1682-3974 / DOI: 10.3923/ajps.2013.208.213

Vascular Bundle Distribution Effect on Density and Mechanical Properties of Oil Palm Trunk

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Abstract: Palm oil tree (*Elaeis guineensis* Jacq.) is a plant species which belong to monocotyledons. The Oil Palm Trunk (OPT) is composed of vascular bundles and parenchyma as ground tissue which determine the properties of the wood. This study was conducted to find out the effect of the vascular bundles toward the density and mechanical properties of OPT in vertical and horizontal direction. The results showed that in horizontal position (outer to the center zone of OPT), the greater number of the vascular bundles contained in trunk made the density value and the mechanical properties greater but in vertical position showed otherwise. The number of vascular bundles is not the only factor that determines the density and mechanical properties of OPT. The top section of OPT has a lower density and mechanical properties than the bottom even though the number of vascular bundles can be greater. This happens because the vascular bundles in the top are composed by the younger cells than the bottom.

Key words: Oil palm trunk, vascular bundles, the vertical and horizontal position, density and mechanical properties

INTRODUCTION

Palm oil tree (*Elaeis guineensis* Jacq.) is a plant species which belong to monocotyledons. Oil Palm Trunk (OPT) is a non-wood lignosellulosic material (Hashim *et al*., 2011) and its anatomical structure is different with wood in general (Tomimura, 1992). The main components of OPT are vascular bundles and parenchyma tissue. Both components are essential to the basic properties (Tomnilson, 1961). Vascular bundles in the OPT are not evenly spread but concentrated on the outer and spread toward the center zone of the OPT (Tomnilson, 1961). Based on the depth of the OPT (horizontal), the number of vascular bundles decreases towards the inner of the trunk (Shirley, 2002; Erwinsyah, 2008) while from the bottom to the top of the OPT (vertical) it tends to increase in number (Lim and Khoo, 1986). The number of vascular bundles is the closest relative parameter to the density and mechanical properties of the OPT, especially in the depth direction of the trunk. The density and mechanical properties of the OPT tend to increase within increasing number of vascular bundles (Khoo *et al*., 1991; Prayitno, 1995; Bakar *et al*., 1998, 1999; Balfas, 2006; Ratanawilai *et al*., 2006; Erwinsyah, 2008; Iswanto *et al*., 2010). However, this conclusion is obtained based on the analysis of the depth direction only on each specific height. Lim and Khoo (1986) reported that the number of vascular bundles increased from the bottom to the top of the OPT but the density and mechanical properties were decreasing. Cells making up the vascular bundles at the top of the OPT are still young age than those at lower levels and the growth is still influenced by the apical meristems. Young cells would have different properties than mature cells. Therefore, besides influenced by the number of vascular bundles, density and mechanical properties the OPT are influenced by the height of the trunk also. The top of the OPT may have a proportion of vascular bundles more than the bottom, however, because the vascular bundles are composed by young cells, the density and mechanical properties of the OPT at top section may be lower than the bottom. This study has more details in observations.

MATERIALS AND METHODS

The OPT used in this study were harvested from PTPN 7 Lampung, Indonesia. Altogether, two OPT of 20 year-old palms were harvested. Samples used were derived from a variety of depth or heights level of the OPT. The samples were taken from 2 m (bottom), 4 m

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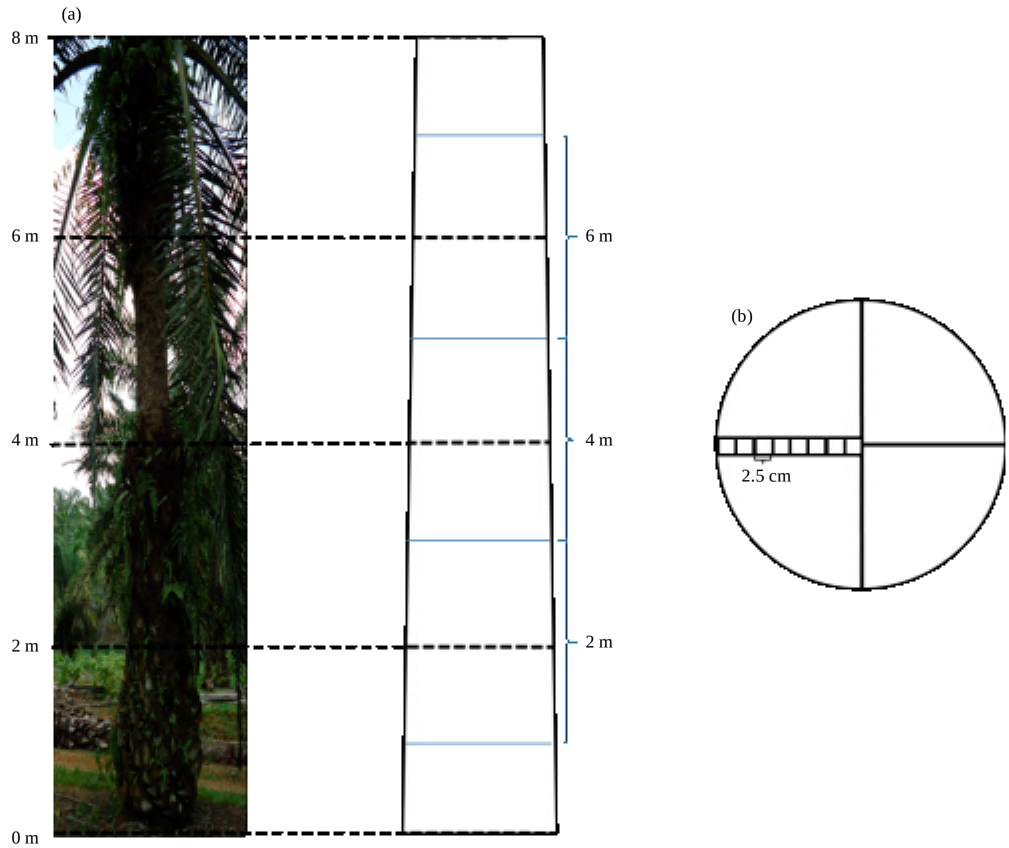

Fig. 1(a-b): (a) Test sampling distribution of vascular bundles, density and mechanical properties at various heights level of oil palm trunk and (b) Sampling distribution of the vascular bundles of physical mechanical properties of the outer to the center of the OPT

(middle) and 6 m (top) from the base of the OPT. Based on the depth from outer to the center zone of the OPT with 2.5 cm distance multiples, observation samples from each height were sorted. The samples to calculate the distribution of vascular bundle are in the disk form with a thickness of 5 cm (Fig. 1). The sample size and testing standard of density and mechanical properties refer to British Standard 373: BSI, 1957. Prior to testing, all samples were conditioned in the condition chamber to attain Moisture Content (MC)±14%. The total of sample test is 48 per parameter wood properties. Testing of mechanical properties is using a Universal Testing Machine (UTM) Instron model 330.

The distribution of vascular bundles is defined as calculation of the number of vascular bundles per unit area (cm^2). Calculations are using a magnifying glass (10 times). Extensive observations are in the form of an equilateral tetrahedron (2×2 cm). Observations start from the outers toward the center zone at various heights level. The results of the research data were analyzed by regression analysis to find the relationship between the distribution of vascular bundles cm^{-2} and the density and mechanical properties of the OPT. This statistical data processing is using Microsoft Excel 2007 software.

RESULTS AND DISCUSSION

The OPT is an organic material composed of diverse cells that are fiber, vessel or metaxylem, protoxylem, protophloem or sieve tubes, axial parenchyma, stegmata and companion cells (Tomnilson, 1961; Lim and Fujii, 1997). Those cell components are a constituent of the vascular bundles. Vascular bundles are anantomical component which played the most important role on the properties of the OPT. The distribution of vascular bundles has many variations in the OPT. The number of vascular bundles decreases from the center to the outer zone of the OPT and from the top to the bottom of the OPT. The number of vascular bundles is negatively correlated with distance of the test sample from the outer to the center, on the contrary it is positively correlated with the height of test sampling (Table 1).

Density and mechanical properties of the OPT declined from the outer to the center (Fig. 2) but based on trunk height level, density and mechanical properties increased from the top to the bottom (Fig. 3). Being outer toward the center zone caused extensive number of vascular bundles unity. The vascular bundles contributes

Table 1: Correlation between vascular bundles with horizontal and vertical position on OPT

Correlation	Height (%)	Distance from outer to center (cm)	Vascular bundles (cm^2)
Height (%)	1		
Distance from outer to center (cm)	0	1	
Vascular bundles (cm^2)	0.248446186	-0.82357543	1

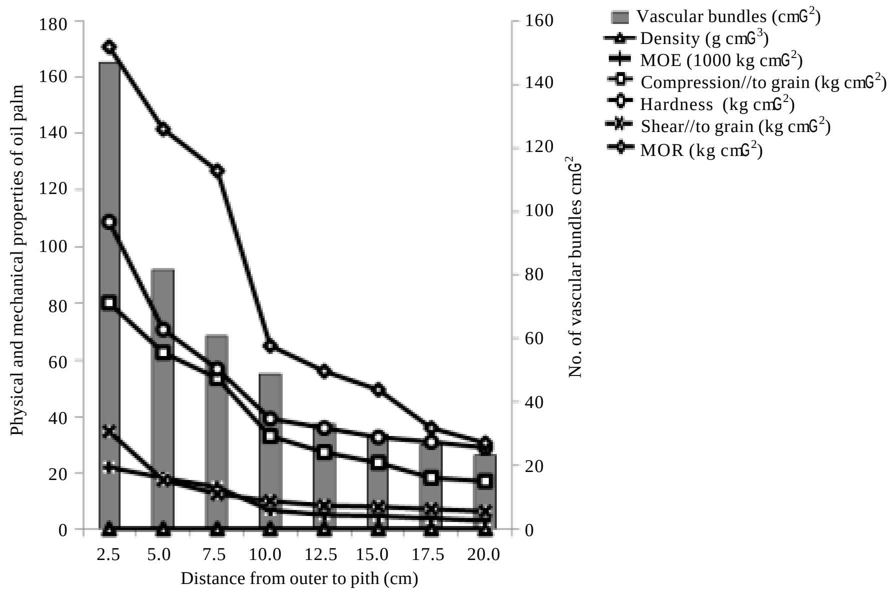

Fig. 2: Average density and mechanical properties and the No. of vascular bundles: Outer to the center of the OPT

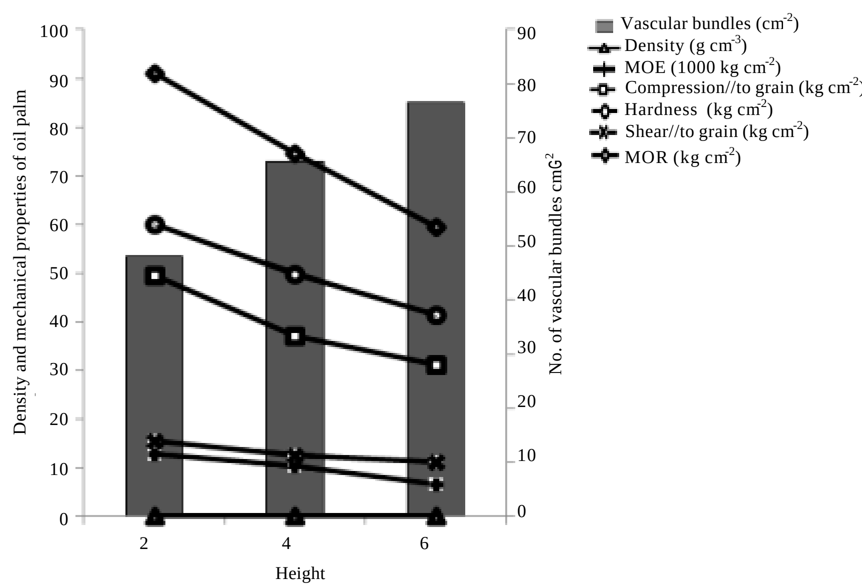

Fig. 3: Average density and mechanical properties and the No. of vascular bundles in the Bottom (2 m), middle (4 m) and top (6 m)

reviewed in a horizontal position, the number of vascular bundles was positively correlated with the density and mechanical properties. However it was negatively correlated when viewed in the vertical direction.

According to Lim and Khoo (1986) differences in density and mechanical properties of the OPT from the to density and mechanical properties of the OPT so as the greater number of the vascular bundles, the OPT properties is increasing as well. One of component constituent cells of vascular bundles is fiber cells. At the outer zone of the OPT, the fiber is shorter than the inside but has a smaller diameter and thicker cell walls. These thick wall fibers shows higher cellulose content and make the material becomes stronger (Shirley, 2002). He further reported that the number of cell wall layers decreases from the outer to the center zone and from the bottom to the top of the OPT.

More proportion of vascular bundles on the outer than the center zone proves less proportion of parenchymal tissue at the outer than the center zone. Parenchyma is a living tissue that functions physiologically as a store of food reserves. Fiber, protoxylem, metaxylem and phloem coalesce into vascular bundles, a network that serves as reinforcing and transport systems in the OPT. A large proportion of parenchyma on the center zone of the OPT shows that the center zone of the OPT has a dominant function as a store of food rather than a structural function. This causes the density and mechanical properties of outer zone of OPT are higher than the center zone. Smaller proportion of parenchyma on the outer of the OPT serves as a reinforcement trunk more than its physiological function so that the outer of the OPT is always more powerful than the center zone. Based on their chemical composition, α-cellulose content of the vascular bundles is greater than in the parenchymal tissue 42.51 and 9.03%, respectively (Abe *et al*., 2013). The more the proportion of vascular bundles in the OPT, the higher the α-cellulose contains. This makes the outer zone of the OPT has a density and higher mechanical properties compared to the center zone High density OPT is always more powerful than low density. There is a close correlation between the densities with the strength of the OPT. The composition of such a unique cell (the outside is more powerful than the inside) is an example of a natural setting that gives the maximum moment of inertia of the OPT to prevent bending and deflection of symptoms so that the OPT is stronger to withstand the load during his lifetime.

In contrast to the vertical direction despite the increased number of vascular bundles from the bottom to the top, the density and mechanical properties were decrease. According to Lim and Khoo (1986) this happens because of the age of the vascular bundles at the top are younger than the bottom. During its growth the cells in the top portion of the trunk is influenced by the apical meristems so it has not perfectly differentiated. The younger cells tend to be soft and have low density compared to older cells due to incomplete lignification process. Lignin is a natural polymer that combines the power and flexibility of cellulose in the cell wall. Lignin also fills the space between the middle lamella so that the OPT become tougher. Lignin binds to cells so that the fibers can work together simultaneously during weight-bearing. The perfectly lignification cells have better mechanical physical properties than the young. Density of vascular bundles decreases from the bottom to the top of the OPT (Rahayu, 2001). The number of cell wall layers of fibers increases from the bottom to the top of the OPT. The thicker the cell wall, cellulose content is also increasing so that the strength of the material is also higher (Shirley, 2002). Fiber cells are the largest components of the vascular bundles than the others so they greatly affect their properties.

A model with a dummy variable is then tried to estimate the effect of the number of vascular bundles at different heights level on the density and mechanical properties of the OPT. The model built is:

$$y = \alpha+bx+cx^2+dz_1+dz_2+\varepsilon$$

Where:

y	=	Density or mechanical properties (MOE, MOR, compression parallel to grain, hardness and shear parallel to grain)
x	=	No. of vascular bundles
z1 and z2	=	Binary dummy variables (binary dummy variables) that represents the height of the OPT origin sample
a	=	Constant
b, c, d	=	Regression coefficient
ε	=	Residual

The model is able to explain most of the variation in the density and mechanical properties of the OPT with a coefficient of determination (R^2) of 82 -89% (Table 2). As shown in Table 2, both measured variables (number of vascular bundles and sample height position origin) show significant effect on the density and mechanical properties (MOE, MOR, compression parallel to grain,

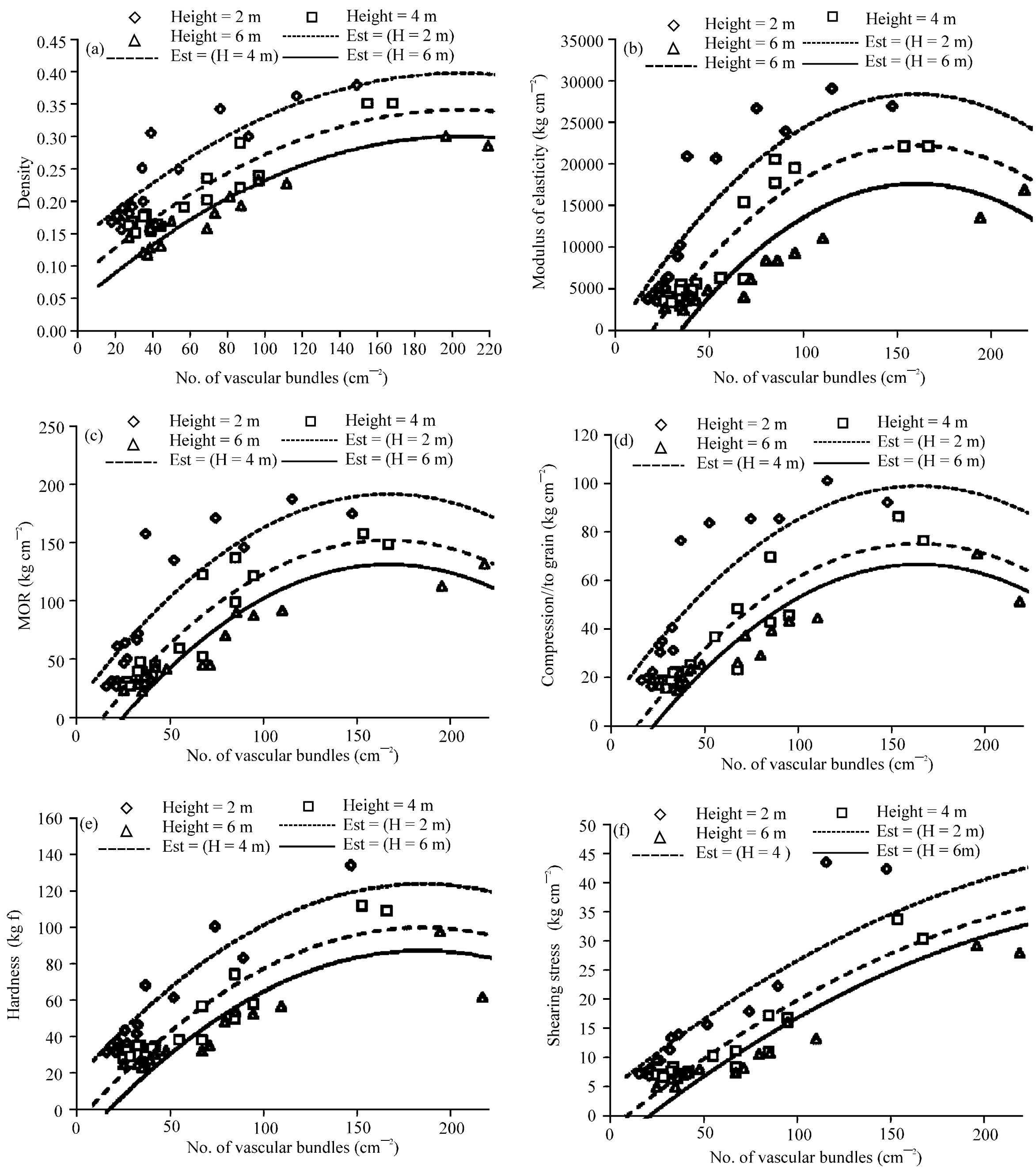

Fig. 4(a-f): Effect of No. of vascular bundles of the (a) Density and mechanical properties of wood at a heigh level of 2, 4 and 6 m of the OPT, (b) Modulus of elasticity, (c) MOR, (d) Compression/to grain, (e) Hardrness and (f) Shearing stress

hardness and shear parallel to grain) of the OPT. In general, the greater number of vascular bundles contained in the OPT, the density and mechanical properties were increase (Fig. 4). Besides being influenced by the number of vascular bundles, density and mechanical properties of the OPT are also influenced by the location of the origin of the OPT height sampling tests. As shown in Fig. 4, curve number of vascular bundles with density and mechanical properties of the OPT to the top is always under the base curve. Top section of the OPT has a lower density and mechanical properties than the bottom even though the number of vascular bundles can be greater.

Table 2: Summary of regression coefficient and p-value relationship between the No. of vascular bundles (x) at various heights (z1, z2) with the density and mechanical properties of OPT

	Density		MOE		MOR		Compression parallel to grain		Hardness		Shear strength	
Parameter	Coefficients	p-value	Coefficients	p-value	Coefficients	p-value	Coefficients	p-value	Coefficients	p-value	Coefficients	p-value
Intercept	0.138244	0.0000	-195.32	0.8950	10.7426	0.2368	09.0036	0.0676	16.2425	0.0030	4.2760	0.0134
z_1	-0.039764	0.0001	-4505.45	0.0005	-20.3802	0.0072	-08.4186	0.0352	-12.3631	0.0048	-3.1278	0.0240
z_2	-0.056093	0.0000	-6236.96	0.0000	-39.3701	0.0000	-23.9807	0.0000	-23.1988	0.0000	-6.7963	0.0000
x	0.002553	0.0000	358.06	0.0000	02.1710	0.0000	01.1047	0.0000	01.1523	0.0000	0.2688	0.0000
x^2	-0.000006	0.0000	-1.12	0.0000	-00.0065	0.0000	-00.0034	0.0000	-00.0031	0.0000	-0.0004	0.0464
R^2	0.008807		0.8369		00.8409		00.8260		00.8490		0.8529	
SE	0.000249		3323		20.23		10.85		11.64		3.7500	
n	48.000000		48		48		48		48		48.0000	

CONCLUSION

The density and mechanical properties of OPT is affected by the number of vascular bundles. The greater number of vascular bundles makes the density and mechanical properties better. But the number of vascular bundles is not the only factor that determines the density and mechanical properties of OPT. The top section of the OPT has a lower density and mechanical properties than the bottom, even though the number of vascular bundles can be greater. This happens because the vascular bundles of top section are composed by the young cells while the bottom section are composed by mature cells.

ACKNOWLEDGMENTS

We wish to thank PTPN 7 Lampung which has provided the raw material for this study and this research was sponsored by MP3EI Research Skim, Directorate General of Higher Education, Ministry of Education and Culture Republic of Indonesia.

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